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R. A. Lundgren

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Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
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Pacific Northwest Laboratory
Richland, Washington 99352

SUMMARY

Pacific Northwest Laboratory (PNL) has completed a successful technical demonstration of simulated reactor vessel sectioning using the combined techniques of air arc gouging and flame cutting.

A 4-ft x 3-ft x 9-in. thick sample was fabricated of A36 carbon steel to simulate a reactor vessel wall. A 1/4-in. layer of stainless steel (SS) was tungsten inert gas (TIG)-welded to the carbon steel. Several techniques were considered to section the simulated reactor vessel: An air arc gouger was chosen to penetrate the stainless steel, and flame cutting was selected to sever the carbon steel. After the simulated vessel was successfully cut from the SS side, another cut was made, starting from the carbon steel side. This cut was also successful. Cutting from the carbon steel side has the advantages of cost reduction since the air arc gouging step is eliminated and contamination control because the molten metal is blown inward.

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INTRODUCTION

As the number of nuclear facilities that are taken out of service increases, the need to develop economic methods to decommission the facilities becomes extremely important. Decommissioning options include: safe storage, where the facility is maintained in a safe condition to insure public safety; entombment, where the facility is cleaned coupled with confinement in monolithic structures; or dismantlement, where radioactive equipment and materials are sectioned and removed from the facility.

As part of the Sectioning Technology task of the Decontamination and Decommissioning (D&D) Facilities-Technology Program, Pacific Northwest Laboratory (PNL)[a] was asked to investigate, select, and technically demonstrate a workable sectioning technique for severing a 9-in. thick simulated carbon steel reactor vessel wall that had been weld clad with a 1/4-in. stainless steel (SS) overlay. The cutting of the vessel wall was to be done from the SS-clad surface. The cutting operation involved two steps: penetrating the SS overlay and severing the carbon steel.

A simulated reactor vessel wall sample was fabricated from A36 carbon steel. The 4-ft x 3-ft x 9-in. sample was faced with 1/4 in. of 308 SS that had been tungsten inert gas (TIG)-welded to the carbon steel.[b] Various cutting methods were evaluated, and the combined techniques of air arc gouging and flame cutting were used to sever the sample.

The remainder of this report discusses the conclusions and recommendations that were reached, the criteria used in selecting a cutting process, the processes that were chosen (air arc gouging and flame cutting), sample preparation, and the results of the cutting operation.

(a) Operated for the U.S. Department of Energy (DOE) by Battelle Memorial Institute.
(b) Pressure vessel material was not used due to cost and delivery time constraints.

CONCLUSIONS AND RECOMMENDATIONS

The combined techniques of air arc gouging and flame cutting proved to be a viable process for severing reactor vessel walls. The air arc gouger easily penetrated the 1/4-in. SS overlay, and the flame cutting equipment cut through the 9 in. of carbon steel with no operational problems.[a] The simulated vessel wall was also cut from the carbon steel side, thereby eliminating the air arc gouger step and controlling external contamination.

Based on the successful initial demonstration, the following recommendations need to be considered for use of this process in the field:

- develop equipment for manipulating the air arc gouger/flame cutter remotely, such as robotic devices that could be used from one job to the next
- develop an air arc gouger for remote underwater operations; underwater cutting may be desirable as a method of containing particulates and combustion products
- investigate other techniques for penetrating vessel walls, such as burning bars, conical-shaped explosive charges, or arc lances
- obtain real-time/cost estimates for actual in-reactor cutting operations to establish a data base for sectioning operations
- consider cutting the vessel wall from the carbon steel side.

(a) A videotape of the demonstration has been produced and is available.

EVALUATION OF CUTTING TECHNIQUES

Selecting a sectioning technique to dismantle a nuclear reactor will probably be unique to the specific reactor. Boiling water reactors (BWRs) and pressurized water reactors (PWRs) are the two common types of reactors that will be encountered. Wall thicknesses range from 5 to 8 in. in BWRs and 8 to 11 in. in PWRs.[(2)] For this cutting operation the sample was modeled after the Shippingport reactor, which is an experimental PWR-BWR-breeder reactor with a vessel wall 9-1/4 in. thick (9-in. carbon steel and 1/4-in. stainless steel).

SELECTION OF CUTTING TECHNIQUES

Several criteria were identified for selecting the appropriate techniques for the two-step process of penetrating the SS cladding and severing the 9 in. of carbon steel. The equipment that was chosen had to be:

- easy to manipulate remotely to reduce radiation exposure to decommissioning personnel
- commercially available
- proven to be reliable in industry
- economical in terms of capital and manpower
- versatile
- operable in various environments (such as in air or underwater).

Several types of cutting equipment were considered for the sectioning operation; brief descriptions are given below.

Arc Saw. This technique was ruled out because it is difficult to manipulate, capital intensive, and requires substantial maintenance.[(3)] However, the arc saw did meet the remaining criteria and it could completely cut through the vessel wall.

Plasma Torch. This technique was also easily ruled out because leading manufacturers of this type of equipment stated that there are no plasma torches on the commercial market that could cut the 9-1/4-in. thick wall. Some consideration was given to using the plasma torch to gouge away the SS cladding; however, after consulting with manufacturers, it was concluded that use of the plasma torch would not be feasible. In fact, damage could result from molten metal blowing back on the plasma torch, which could cause electrical shorts and extensive damage to the cutting system.

Milling and Other Mechanical Techniques. Although these methods met most of the criteria, they were not selected because they are usually capital intensive, difficult to manipulate due to their massive size, and would require large, expensive manipulating equipment.(3)

Air Arc Gouger. This equipment, shown in Figure 1, was selected to penetrate the 1/4-in. SS cladding because it is not costly, it is commercially available, it is used in industry on a daily basis, and it could be used for both in-air and underwater cutting. However, remote-controlled equipment would have to be developed for underwater use. The gouger could make a single or multiple passes over the vessel wall sample to remove the SS cladding and expose the carbon steel.

The second part of the operation involved severing the 9 in. of carbon steel. Flame cutting was chosen for this part of the demonstration because it is currently used in everyday heavy industry, it is not capital intensive, it can be remotely manipulated, and it can be used underwater as well as in air.(4) It should be noted, however, that special gas mixtures and torch heads would be required for underwater cutting. The flame cutting equipment is shown in Figure 2.

DESCRIPTION OF CUTTING PROCESSES

The air arc gouging process requires a torch, carbon electrodes, a source of compressed air, and a dc power supply. Electric power and air are supplied to the torch through an air-cooled power cable. To initiate a gouge, an arc is struck between the carbon eletrode and the work piece. As the work piece becomes molten, a stream of compressed air from the torch head blows away the molten metal. Because the metal melts rather than oxidizes, arc gouging is effective on both ferrous and nonferrous alloys. A schematic of the air arc gouger is shown in Figure 3.

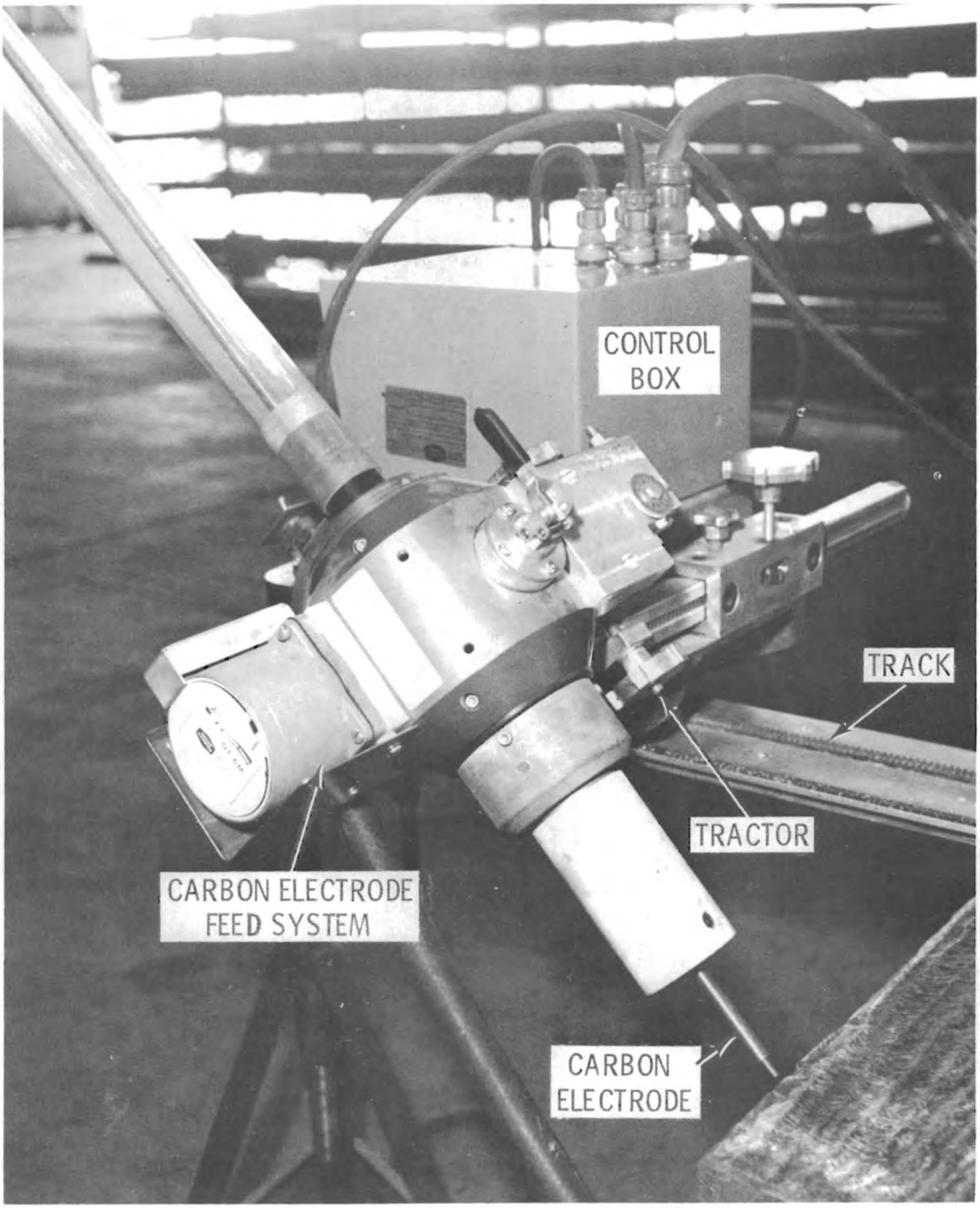

FIGURE 1. Air Arc Gouger

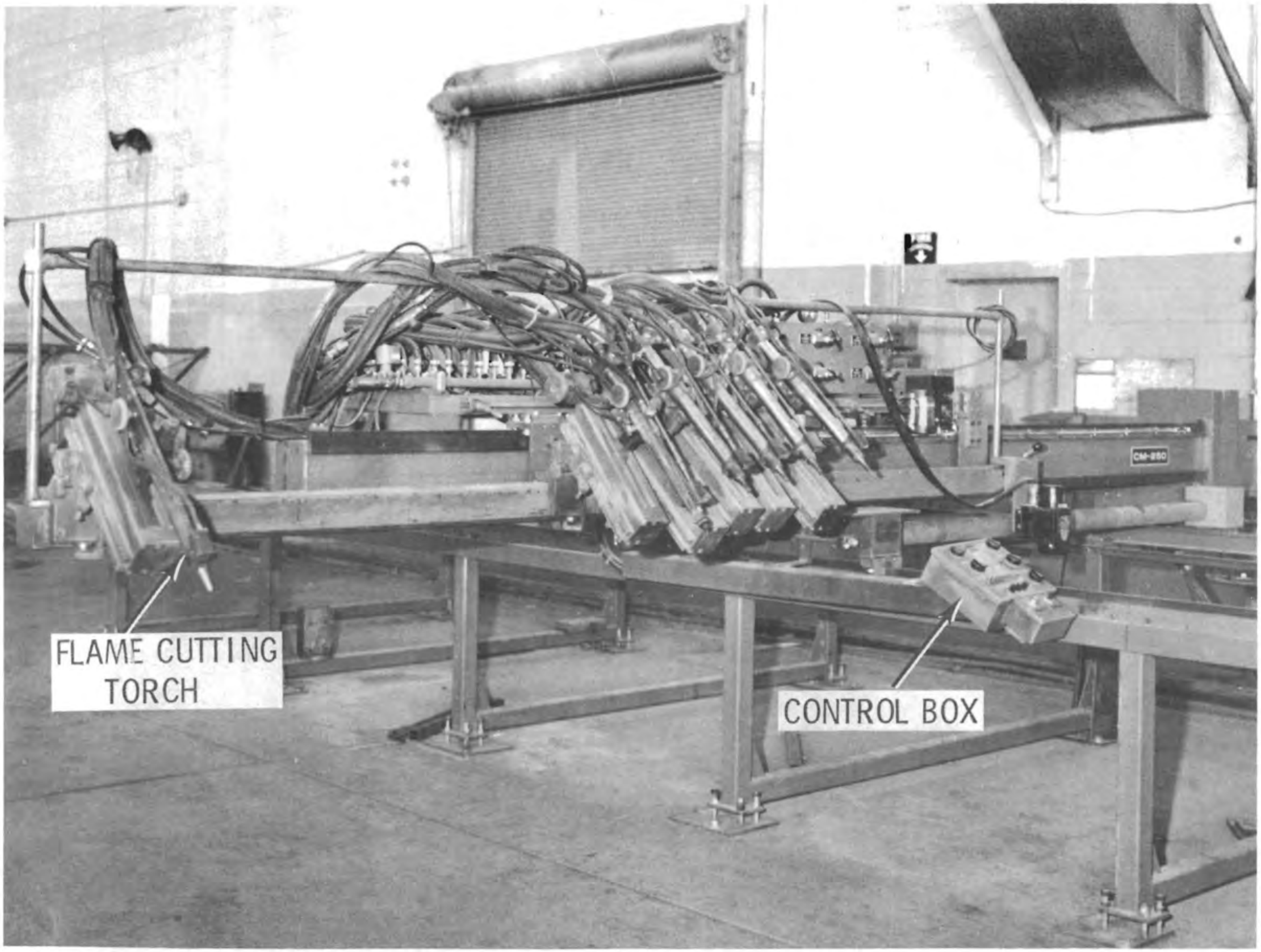

FIGURE 2. Flame Cutting Equipment

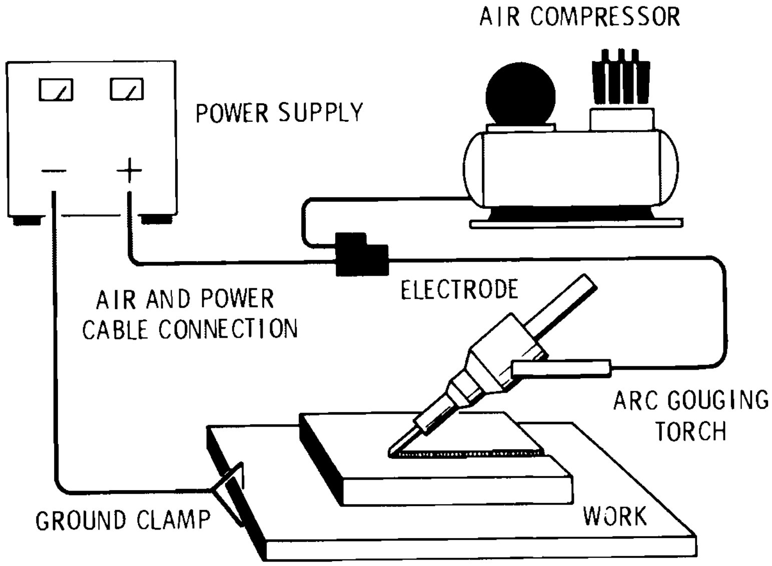

FIGURE 3. Schematic of Air Arc Gouging Technique

The principles of flame cutting are simple. A preheat flame heats a spot on the work piece to a "cherry-red" heat. Once this temperature is reached, an oxygen jet is turned on and an exothermic reaction takes place producing various iron oxides. The heat from this exothermic reaction melts the work piece, and the excess O_2 that is released by the cutting torch blows the molten material away. A schematic of the flame cutting equipment is shown in Figure 4.

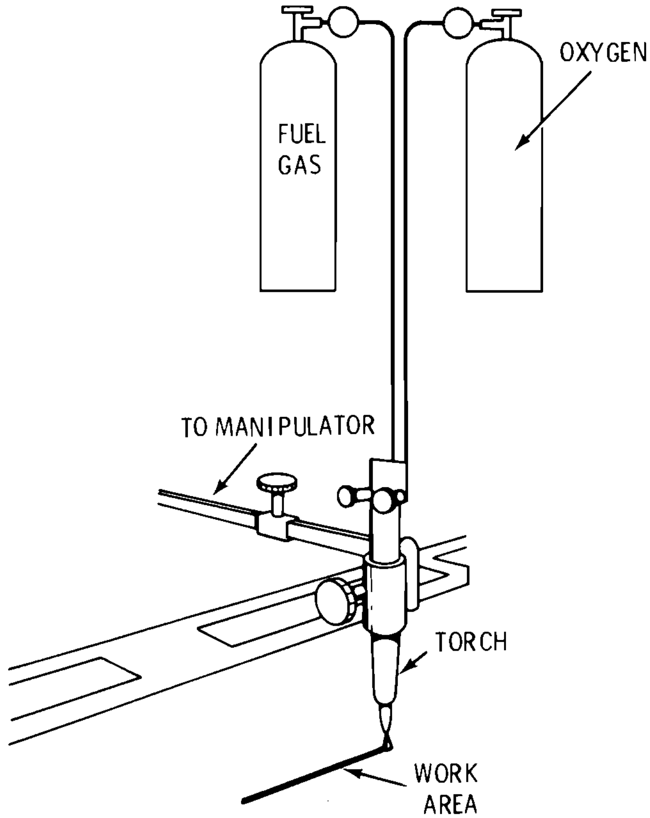

FIGURE 4. Schematic of Flame Cutting Equipment

SECTIONING DEMONSTRATION

Interest in viable sectioning techniques for nuclear reactor components is growing because the number of reactors requiring decommissioning is increasing. The purpose of this technical demonstration was to indicate that a viable, economic sectioning technique currently exists that can be adapted for use in the nuclear industry.

SAMPLE PREPARATION

This project was undertaken to show the feasibility of using these two techniques--air arc gouging and flame cutting--to section a reactor vessel wall with the following specifications:

- 1/4-in. 304L SS on 9 in. of SA 302B carbon steel
- stainless steel roll-bonded to carbon steel on wall sections
- stainless steel TIG-welded overlay on top and bottom of reactor vessel.

For the technical demonstration, however, the reactor vessel wall was simulated; and the sample was fabricated to the following specifications:

- 4-ft x 3-ft x 9-in. sample size
- 1/4-in. 308 SS TIG-welded on 9 in. of A36 carbon steel.

RESULTS

An initial test of the technique took place on August 28, 1980, in Moses Lake, Washington. An air arc gouger that is commonly used in industry was used for the gouging phase of the test. The gouger fits on a cutting machine tractor and moves at a rate of 20 in./min. The gouger penetrated the stainless steel, exposing the carbon steel. When this first phase of the operation was completed, flame cutting was used to sever the 9 in. of carbon steel. The test arrangement with the air arc gouger in place is shown in Figure 5.

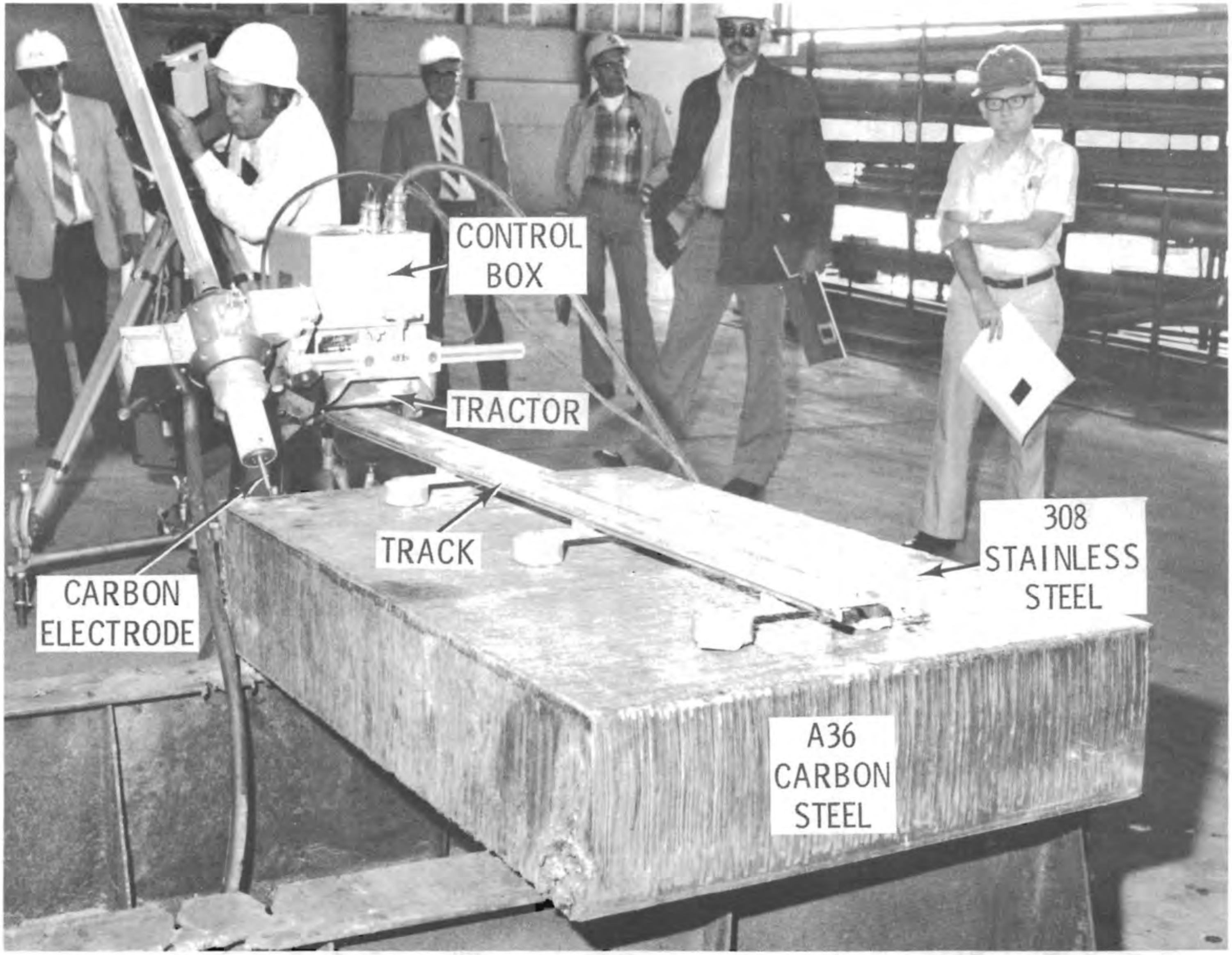

FIGURE 5. Test Arrangement With Arc Gouger in Place

Three runs were made to establish the operating conditions needed to penetrate the SS cladding; they are described below.

- Cut 1. The air arc gouger was operated at a travel speed of 28 in./min and a rod feed rate of 1 in./min. The test was run with an arc voltage of 50 V and an arc current of 280 A (dc), the air pressure was 80 psi, and the gouger operated for 2.5 min before the carbon rod broke due to a misalignment of the rod feed system. At that time the depth of the cut was 3/16 in., which was not adequate to penetrate the SS overlay. The depth of the cut is shown in Figure 6.

- Cut 2. This test was run under the same conditions as Cut 1, and the carbon rod broke after about 2.5 min of operation due to a misalignment of the rod feed system. It can be noted from Figure 7 that the gouge had in fact penetrated the stainless steel.

- Cut 3. For this cut, the gouger was operated at 20 in./min with the rod feeding at almost 2 in./min. The test was conducted with an arc voltage of 44 V and and arc current of 340 A (dc), the air pressure was 80 psi, and the total run time was 2 min 40 sec. At that time the gouger had penetrated the stainless steel by 7/16 in., which was an adequate depth. The successful penetration of the SS cladding is shown in Figure 8. Next, the flame cutting technique was used to sever the simulated vessel completely (~4 ft were cut in 21.5 min). Figure 9 shows the beginning of the flame cutting portion of the test, and Figure 10 shows the completed cut. The preheat conditions were: propylene fuel at less than 1 psi; oxygen pressure at 55 psi; and cutting oxygen pressure at 100 psi.

With Cut 3 the simulated vessel wall was severed, and the feasibility of reactor vessel wall sectioning by the gouging/flame cutting technique was shown. Figure 11 compares the three cuts that were made on the sample.

On September 3, 1980, the cutting operation was repeated for a group of 10 spectators, including representatives from DOE, United Nuclear Corporation

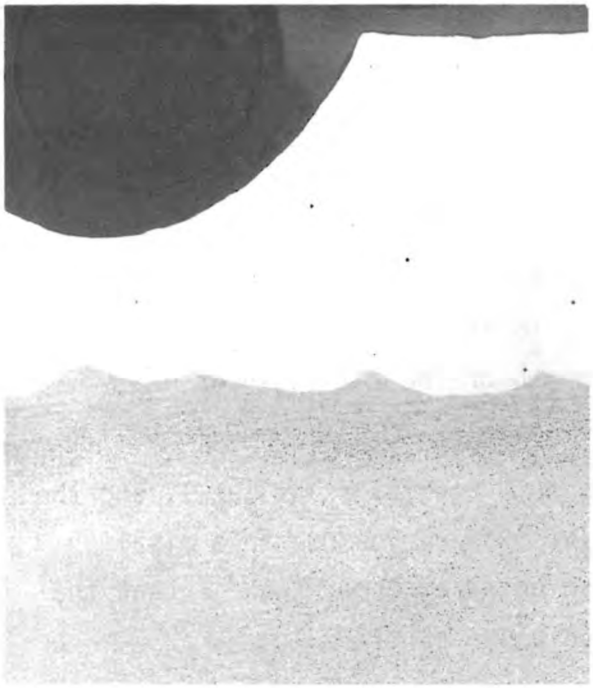

FIGURE 6. View of Cut 1

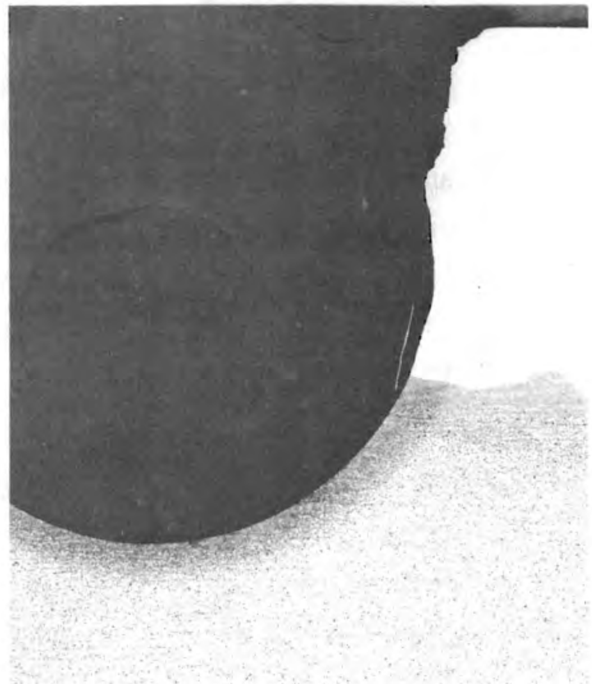

FIGURE 7. View of Cut 2

FIGURE 8. Successful Penetration of Stainless Steel Cladding (Cut 3)

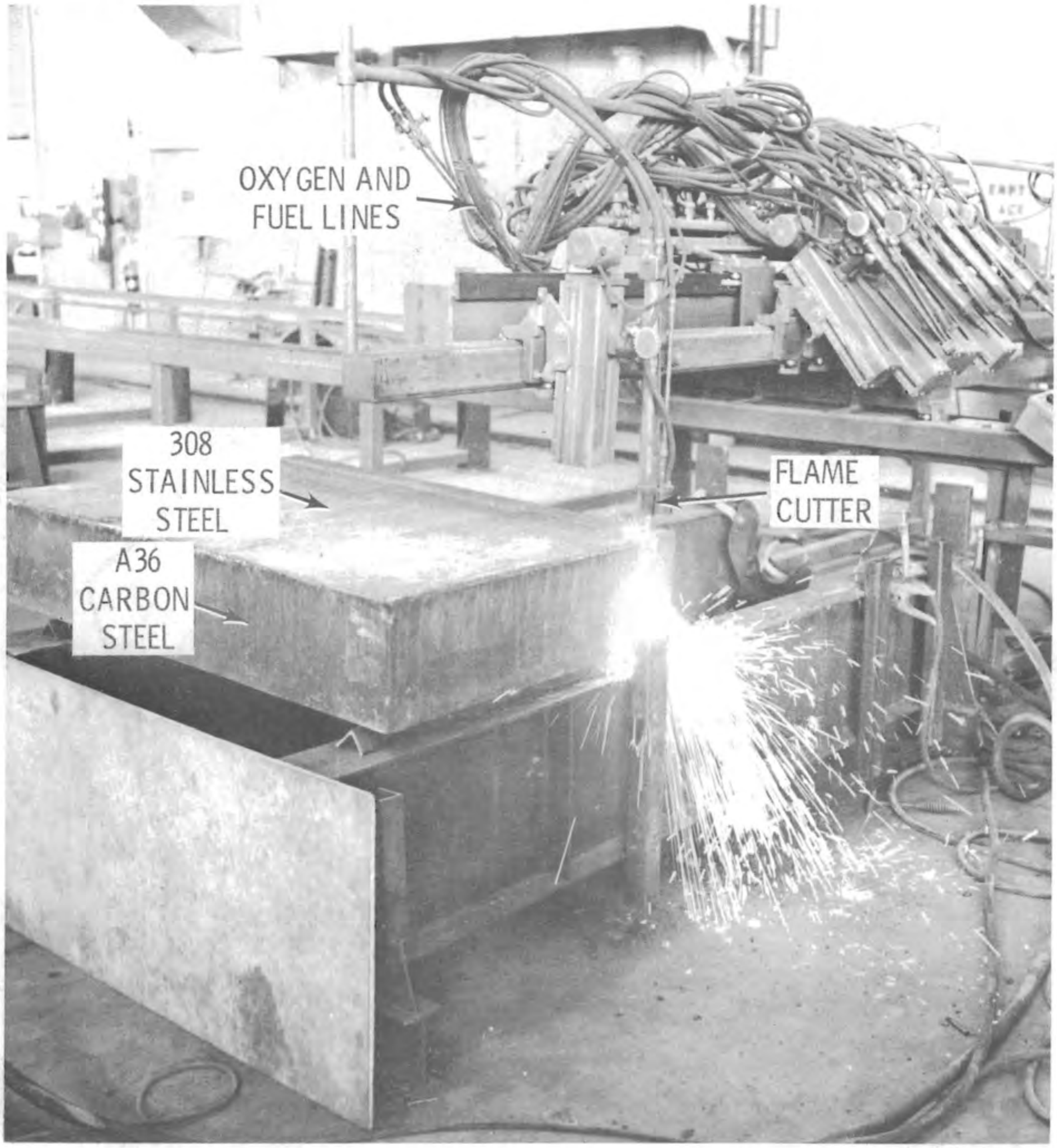

FIGURE 9. Initiation of the Flame Cutting Procedure

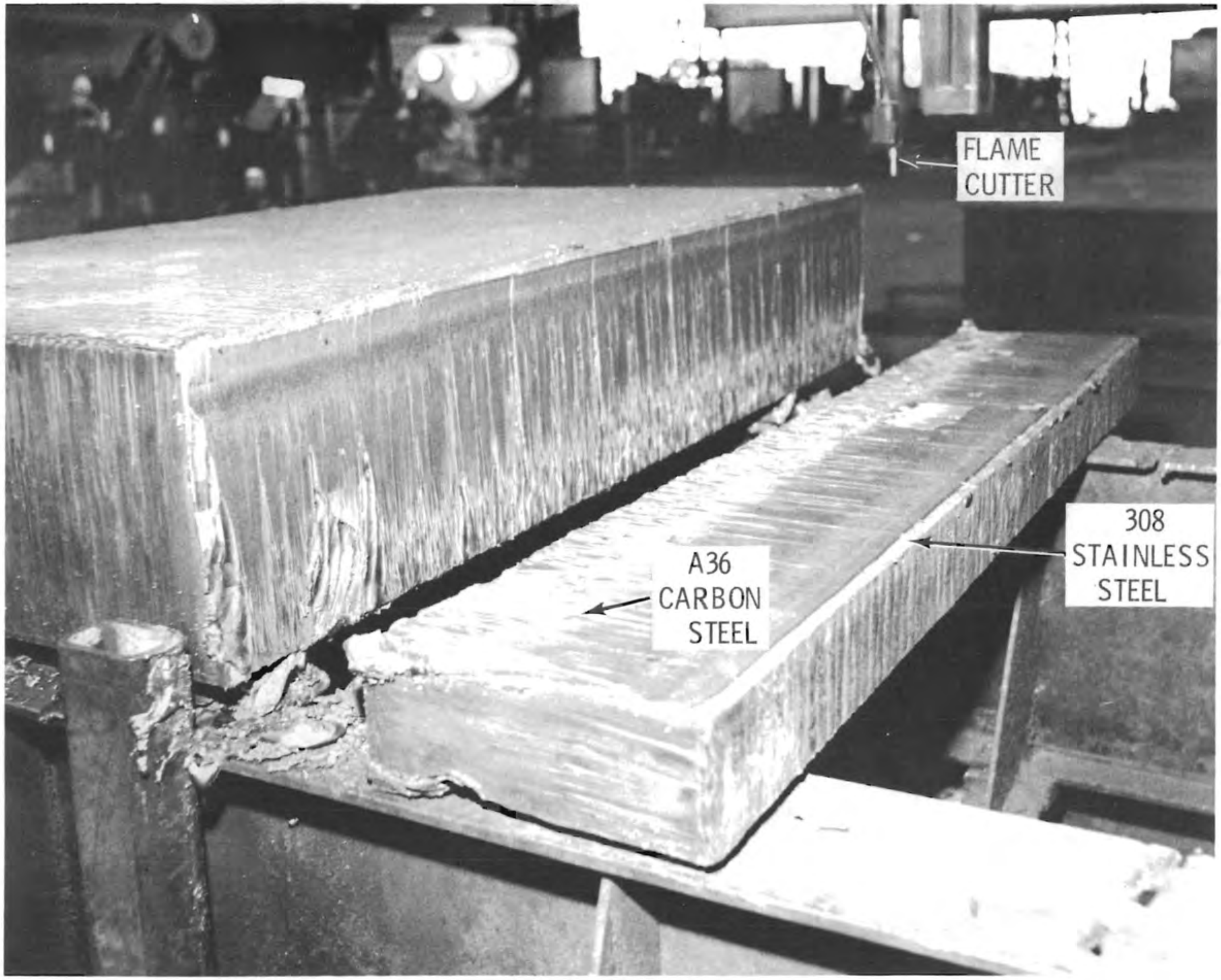

FIGURE 10. View of Completely Severed Sample

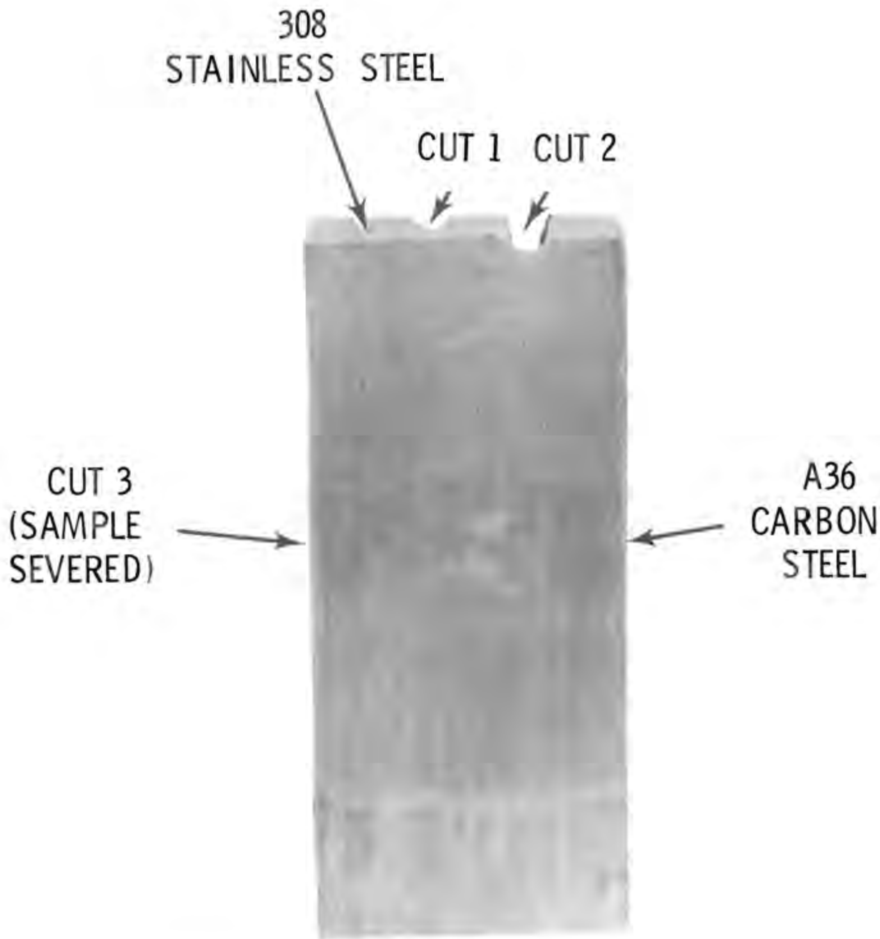

FIGURE 11. Comparison of Cuts 1, 2, and 3

(UNC), and PNL. The air arc gouger penetrated the SS cladding in about 4.5 min, and the flame cutting took approximately 25 min. Both cuts were made without difficulty.

After the first cut was completed, the question arose: Could the simulated reactor vessel wall be cut from the carbon steel side, thus eliminating the need for the air arc gouging step? The same flame cutting parameters were followed as in Cut 3 described above, and a successful cut was made that was somewhat cleaner than the previous cut (probably because the large vessel wall sample was preheated from the previous cut). The advantages of cutting the vessel from the carbon steel side include a cost savings due to eliminating the air arc gouging step and control of contamination because the molten metal would go into the vessel.

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